Escape to Failure: The Qantas Flight 32 Uncontained Engine Failure

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Airbus A380

- The world's largest passenger airliner—the double-deck, wide-body Airbus A380—is powered by four Rolls-Royce Trent 900-series turbofan engines; each capable of producing over 80,000 pounds of thrust. The engines are numbered No. 1 (outermost port engine) to the No. 4 (outermost starboard engine).
- The Trent 900-series engine is a three-shaft, high-bypass ratio design containing three primary compressor/turbine assemblies: a low pressure (LP), an intermediate pressure (IP), and a high pressure (HP) assembly.

Critical Design and Quality Control

- The highly critical and complex nature of A380 aircraft and Trent 972-84 engines shares similarities with many of NASA's own systems. With such complex systems, numerous inter-dependencies exist of a tightly coupled nature that demand regular and open communication between all design, manufacturing, and quality personnel.

Figure 1. Trent 900-Series engines on an Airbus A380.
Source: ATSB

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What Happened

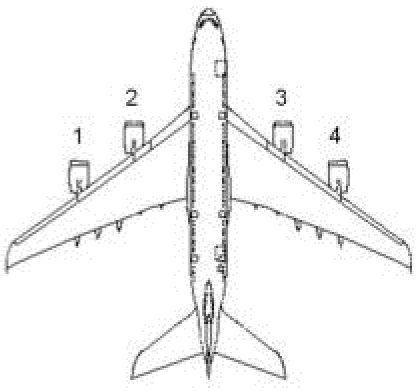

Figure 2: Engine positions. Source: ATSB

- Nov. 4, 2010: Qantas Flight 32 was departing Singapore (SIN), climbing through 7,000 ft at 250 kn. At approximately 10:01 a.m., passengers and crew heard two loud bangs.
- The crew held altitude and heading and received Electronic Centralized Aircraft Monitoring (ECAM) system messages, starting with a No. 2 turbine overheat warning. The crew idled No. 2 while alerting SIN air traffic control (ATC). While attempting to shut down No. 2, the engine failed.
- A fuel system integrity ECAM message prevented fuel transfer or dumping. The crew processed ECAM messages and related procedures. SIN ATC vectored Flight 32 to a holding area east of SIN.
- Less than 1 hour later, the crew descended to SIN with inoperative wing leading edge devices, left engine thrust reverser, spoilers, and reduced braking function.
- At 11:46 a.m., Flight 32 touched down 95 tons overweight and rolled to a stop approx. 500 ft from the end of the runway.
- Fuel spilled onto the tarmac from the port wing as brakes cooled from 1,650 °F. Firefighters doused tarmac with retardant. Engine No. 1 could not be shut down and was drowned by shooting foam into the intake for 3 hours. No injuries were reported.

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Proximate Cause

- The Australian Transportation Safety Bureau (ATSB) determined that the No. 2 engine sustained an uncontained turbine failure and that liberated engine components damaged the aircraft.
- A fatigue crack in the HP/IP oil feed stub pipe allowed oil to leak into a high temperature buffer space and ignite; fire damaged engine integrity. The IP turbine disc separated from the shaft, accelerated, and burst outward in three main pieces, breaching the casing and damaging the aircraft.

Figure 3. A Trent 900 IP turbine disc after an overspeed burst test. Source: Rolls-Royce plc./ATSB

Underlying Issues

The ATSB found that the oil pipe within the HP/IP hub assembly was manufactured with thin wall sections: a nonconformance to design specifications.

Design Intent and Altered Manufacturing Process

- 2006: When the engine moved from design into manufacturing, the pipe needed to be machined after being fitted to an assembly; concealing a geometrically constrained datum (reference point) for the pipe counter bore. Manufacturing Engineers (MEs), with “no process in place for consultation” with designers, introduced a new manufacturing datum for the counter bore that was not constrained with respect to other pipe features. *The new specifications did not constrain a safe thickness for the counter bore of the pipe.*
- A pin was fitted into the pipe to position the assembly for machining; however, the fitting occurred hours before the drilling of the counter bore and the assembly shifted, resulting in an offset bore and thin wall section. The use of the pin as reference undermined both design and the altered manufacturing process.

Inadequate Inspections and Quality Investigation


Figure 4. Damaged wing on Flight 32. Source: ATSB

- The hub assembly passed the Coordinate Measuring Machine (CMM) inspection as the counter bore datum was not inspected against certain features defined during design.
- 2006: CMM programs were created/implemented by inspectors without validation and ME involvement.
- 2007: A major quality investigation into records and CMM inspections uncovered many non-conformances and resulted in involvement from both inspectors and MEs.
- 2009: MEs realized the effect the new datum was having on non-conforming parts; however, their analysis to determine the extent was based on the nine work-in-progress assemblies at the factory. The sample was not large enough to provide results that were representative of the fleet in service.

Aftermath

- Qantas immediately grounded its fleet of A380 airliners.
- Other A380 operators (even those not using Rolls-Royce engines) decided to limit use or ground A380 flights.
- After Qantas' own investigation and analysis of the failure, it reintroduced A380 fleet services on Nov. 27, 2010.
- Rolls-Royce, the Australian Civil Aviation Safety Authority (CASA), and ATSB issued a range of measures to identify and remedy Trent 900 HP/IP hub assemblies with nonconforming oil pipes.
- According to the ATSB, Rolls-Royce has improved quality management systems in respect to managing nonconforming parts, both during manufacturing and service.

Relevance to NASA

Figure 5: Drowning engine No. 1. Source: ATSB

- Complex and critical systems—and their components—require adherence to strict configuration control, workmanship, and process control requirements. In regards to Qantas Flight 32, a breakdown is apparent in communication between the design and manufacturing phase.
- NPR 8735.2B defines critical acquisition items as "Products or services whose failure poses a credible risk of loss of human life; serious personal injury; loss of a Class A, B, or C payload (see NPR 8705.4); loss of a Category 1 or Category 2 mission (see NPR 7120.5); or loss of a mission resource valued at greater than $2M."
- Complex acquisition items are "hardware products which have quality characteristics that are not wholly visible in the end item and for which conformance can only be established progressively through precise measurements, tests, and controls."
- For procurement of critical/complex items, NASA contractors are required to adhere to various higher-level quality and workmanship requirements (e.g., SAE AS9100, J-STD-001, ANSI Z540.3, ANSI ESD S20.20, SAE AS5553), and NASA oversight of contractors is required to include detailed surveillance (e.g., inspections, tests, process witnessing, record review, quality system audits).